Secretary of the Navy Professor of Oceanography

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LONG-TERM GOALS

1. ACOUSTIC OCEANOGRAPHY. Measurements by P. Wadhams from an British submarine have indicated a more rapid thinning of the Arctic ice cover than previous estimates, leading possibly to an ice-free summer by 2016 (*The Economist* estimated by the end of the century, Special Report on the Arctic in the 16 June 2012 issue). Disappearance of the ice cover and the attendant drop in polar albedo has first order consequences that should be monitored during the transition decade. We will study various schemes of polar tomography, possibly involving a polar source and peripheral receivers, with the acoustic sources doing double duty for navigating gliders and AUV's. The ongoing Philippine Sea experiment has led to developments that will be useful in the more difficult polar environment. An attractive feature is the continued collaboration with the Nansen Institute in Bergen.

I have worked on the acoustic properties of the ocean wedge between the sea floor and a floating ice sheet, stretching from the continental grounding line to the ice front (for several hundred kilometers in the Ross Sea). These are the only ocean volumes not yet visited by men. Work is being done to lower instruments through holes drilled through the ice sheets, and by launching AUV's from the ice edge into the interior cavern. Navigation is difficult; GPS is not available under the ice cover. I have been working on a scheme for augmenting these efforts with an application of ocean acoustic tomography to the ocean caverns. Acoustic transponder arrays would be deployed just seaward of the ice edge radiating into the cavern. It is a known (but not well known) property of wedge-like caverns that acoustic rays are refracted away from the wedge apex back to the wedge opening (just as they are refracted away from the deep waters of the polar ocean back towards the surface). The broad Ross Sea ice shelf has the ideal geometry for such an experiment. For logistic reasons it is more likely it would take place in the arctic, and required acoustic receivers lowered through the ice sheet near the grounding line.

The principal cause of the global sea level rise is the melting of Antarctic and Greenland ice sheets floating on a relatively warm ocean; melting at the ice surface is a secondary consideration (This is a change from the accepted viewpoint of only a decade ago). Thermal expansion of the warming ocean is also a lesser factor. An acoustic under-the-ice experiment could led to an understanding the melting processes and hopefully the IPCC prediction for the rise in global sea level by the year 2100 is 0.3 to 2 meters. The error bars are so large as to make

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the prediction almost useless. A 1m rise would require the repopulation of more than 1 million people! Accordingly the global rise in sea level has been declared a national security issue.

2. PHYSICAL OCEANOGRAPHY. I have continued my work on sea surface roughness as related to wind drag. The relevant statistics are associated with mean square slope (not elevation). The principal contribution to slope variance is from waves shorter than 20 cm, a distinct part of the spectrum of waves shorter than the classical Phillips gravity wave spectrum. Given that so much of ocean dynamics is the result of a the variable wind drag, understanding the ultragravity (ug) waves is a first order problem in many ocean processes. Recent results are summarized in two papers: an analysis of the hydrophone measurements at the mid-Pacific H20 station on (rather surprisingly) the deep sea bottom (Farrell and Munk 2012) and a theoretical analysis (Young, Wolfe and Munk 2012), both in press. The overall situation is that there are still no good at sea direct measurements of the 2-D ug spectrum; laboratory measurements fall short regarding the surprisingly large crosswind slope components. We are left dependent on remote sensing from 500 km above and 5 km beneath the sea surface, with good enough statistics but unreliable interpretation. And we have as yet no theory for the ug wave generation. I am requesting continuation of support for my Navy Chair in the hope that we can put an end to this intolerable situation.

OBJECTIVES

1. To monitor the Arctic Ocean during the present transition towards an ice-free summer.
2. To monitor the ocean caverns between the floating ice sheets and the sea floor.
3. To understand the transition spectrum from classical gravity waves to capillaries.
4. To produce better wind maps over the oceans.

APPROACH.

1 and 2: Sea-going experiments using Ocean Acoustic Tomography.
3 and 4: Analysis of existing sea floor records at and near the Hawaiian Ridge

WORK COMPLETED

Munk, W. (2011) The Sound of Climate Change: Crafoord Prize Scientific Lecture, *Tellus*, 1-8.

Worcester, P.E., W.H. Munk, B.D. Cornuelle, M.A. Dzieciuch, and K.E. Wage (2011), Exploring an under-ice ocean cavity with sound, paper presented at XXV IUGG General Assembly, Melbourne, Australia, 28 June – 7 July 2011.

Munk, W. (2011) Nansen Center 1986-2011: A View from La Jolla. *Presentations from the Nansen Center´s 25 Years Colloquium*, http://www.nersc.no/news/presentations-nansen-center%C2%B4s-25-years-colloquium-available.

Worcester, P. F., and W. H. Munk (2012), Oceanography in 2030: The role of acoustics in observing the ocean, 2012 Ocean Sciences Meeting, Salt Lake City, Utah, 20–24 February 2012. (POSTER)

Worcester, P. F., W. H. Munk, B. D. Cornuelle, M. A. Dzieciuch, and K. E. Wage (2012), Exploring an under-ice ocean cavity with sound, 2012 Ocean Sciences Meeting, Salt Lake City, Utah, 20–24 February 2012. (ORAL)

Munk, W. and C. Pendarvis (2012) Where the Swell Begins. Groundswell Publication Annual Publication, 5, 242-257, in press.

Dashen, R. and W. Munk (2012) A Model of Ocean Noise, JASA Special Issue, in press.

Farrell, W. and W. Munk (2012) Surface gravity waves and their acoustic signatures, 1-30 Hz, on the mid-Pacific sea floor, JASA Special Issue, in press.

Young, W.R., C.L. Wolfe, and W.H. Munk (2012) Generation of gravity-capillary waves by instability of shear flow, J. Fluid Mech., submitted.

RESULTS

Three octaves of surface waves (from 2 to 16 Hz) are quite distinct from the classical Phillip spectrum at lower frequencies: their spectrum is not saturated. They play a leading role in the momentum transfer from wind to ocean. The paper by Young et al has demonstrated that this transition spectrum is not associated with instabilities in the surface shear layer.

IMPACT/APPLICATIONS

Wind drag is the most basic forcing function in dynamic oceanography. An understanding of the underlying process (such as surface roughness) should lead to improved prediction of a wide variety of ocean processes.

TRANSITIONS

The gravity to capillary wave transition spectrum may offer some spectral "gaps" with the opportunity for listening to ocean events with a favorable signal to noise ratio. There are interesting opportunities for ASW.

RELATED PROJECTS

Meetings and Invited Talks

- Attended: The Venice Conference: Improving the Capacity to Assess and to Adapt to Climate Change in Urban Coastal Regions; Venice, Italy; 12-15 September 2011
- Invited Talk: *Waves, long and short*, Fourteenth NPAL (North Pacific Acoustic Laboratory) Workshop; Fallbrook, CA; 20 October 2011
- Keynote Address: *Waves, long and short*, Symposium to honour the scientific work of Klaus Hasselmann at the Max Planck Institute for Meteorology; Hamburg, Germany; 09 November 2011

- Keynote Address: *Nansen Center 1986-2011: A View from La Jolla,* Nansen Center 25 Year Colloquium, In Honour of Fridtjof Nansens 150 Year Anniversary; Bergen, Norway; 18 November 2011
- Invited Talk: *Waves, long and short*, National Oceanography Centre Lecture Series; NOC Southampton; 24 November 2011
- Invited Talk: 2012 Distinguished Speakers Series, Riford Center; La Jolla, CA; 26 January 2012
- Invited Talk: *Science and Technology on the Homefront*, 2012 Lecture Series, La Jolla Historical Society; La Jolla, CA; 07 April 2012
- Attended: The American Philosophical Society Annual Meeting; Philadelphia, PA; 19-21 April 2012
- Attended: JASON Spring Meeting; Arlington, VA; 27-29 April 2012
- Attended: The National Academy of Sciences Annual Meeting; Washington, DC; 29 April – 01 May 2012
- Invited Talk: *Wind drag and ultra-gravity waves,* IUGG Conference on Mathematical Geophysics; Univeristy of Edinburgh, 18-22 June 2012
- Attended: Laying of the Keel of the Ocean Class Oceanographic Vessels AGOR 27 & AGOR 28; Anacortes, WA; 17 August 2012

REFERENCES and PUBLICATIONS

Munk, W. (2011) The Sound of Climate Change: Crafoord Prize Scientific Lecture, *Tellus*, 1-8.

Worcester, P.E., W.H. Munk, B.D. Cornuelle, M.A. Dzieciuch, and K.E. Wage (2011), Exploring an under-ice ocean cavity with sound, paper presented at XXV IUGG General Assembly, Melbourne, Australia, 28 June – 7 July 2011.

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